ISBN No. : 978-602-17221-4-5

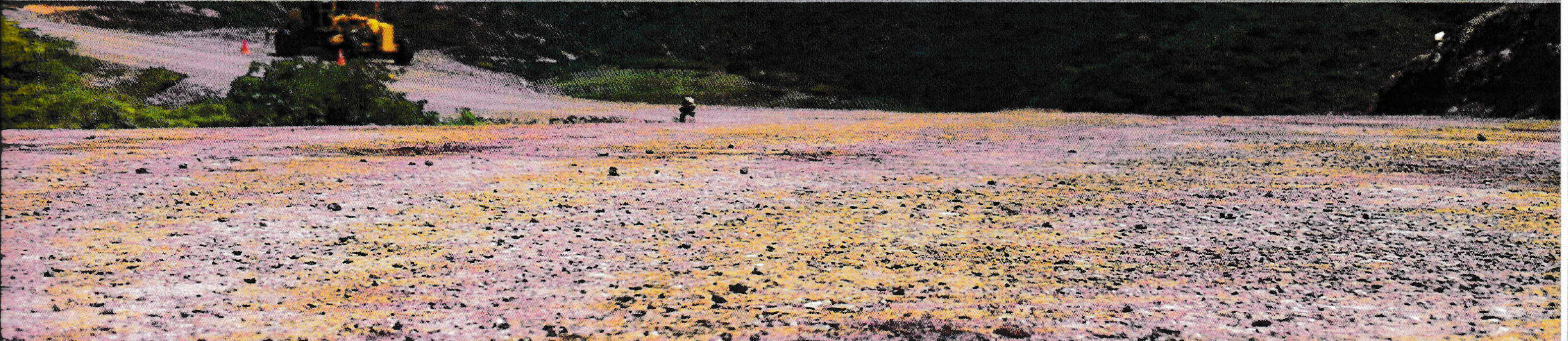
HIMPUNAN AHLI TEKNIK TANAH INDONESIA
INDONESIAN SOCIETY FOR GEOTECHNICAL ENGINEERING (ISGE)
MEMBER SOCIEY OF INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING (ISSMGE)

SIMSG ISSMGE

Proceedings

20th Annual National Conference on Geotechnical Engineering

"Geotechnical Role to Accelerate Infrastructure Construction in Indonesia "



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KATA PENGANTAR

Assalamulaikum Wr. Wb.

Salam sejahtera bagi kita semua.

Puji syukur senantiasa kita panjatkan kepada Tuhan Yang Maha Esa sehingga Pertemuan Ilmiah Tahunan (PIT) Himpunan Ahli Teknik Tanah Indonesia (HATTI) XX ini dapat terselenggara. Bapak Basuki - Menteri PUPERA, para undangan, Keynote Speaker, pembicara, dan seluruh rekan profesi geoteknik yang saya hormati.

Pertemuan Ilmiah HATTI tahun ini mengambil tema "**Geotechnical Role to Accelerate Infrastructure Construction in Indonesia**" dimana peranan profesi geoteknik menjadi salah satu kunci penting agar percepatan pembangunan infrastruktur dapat dilaksanakan dengan efektif dan efisien. Pertemuan ini juga diharapkan dapat mempererat hubungan antar rekan profesi, menjadi ajang bertukar informasi, pengalaman, diskusi maupun jalinan hubungan kerjasama antar profesi.

Pada kesempatan ini, atas nama seluruh anggota panitia penyelenggara, perkenankan saya mengucapkan terima kasih kepada Vantage Commerce sebagai sponsor utama acara ini, maupun para sponsor lainnya. Ucapan terimakasih juga kepada para Keynote Speaker, pembicara, penulis makalah, dan para peserta yang telah berpartisipasi untuk suksesnya PIT-XX 2016 ini. Kami mohon maaf apabila dalam penyelenggaraan acara ini ada kekurangan yang tidak berkenan.

Selamat datang dan selamat berdiskusi, semoga Pertemuan Ilmiah Tahunan ini dapat bermanfaat bagi perkembangan profesi Geoteknik di tanah air. Salam Geoteknik.

Wassalamualaikum Wr Wb,
Jakarta, 15 November 2016
Panitia PIT - XX

Dr. Ir. Pintor T. Simatupang, MT
Ketua

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Auto Power Spectral Density Analysis for Measuring Energy Attenuation in a Layered Soil Site

Sri Atmaja P. Rosyidi
Universitas Muhammadiyah Yogyakarta

Anita Widianti
Universitas Muhammadiyah Yogyakarta

ABSTRAK: Getaran yang berasal dari aktivitas konstruksi, gempa bumi dan pembebanan lalu lintas menjadi penting untuk diperhatikan karena getaran tersebut dapat menyebabkan kerusakan pada struktur. Untuk menganalisis sutau getaran perlu mempertimbangkan beberapa kombinasi faktor yang mempengaruhi getaran tersebut yaitu karakteristik sumber getaran, kondisi setempat, perambatan gelombang seismik dan respon struktur. Pada umumnya, pengurangan getaran terhadap jarak dihasilkan dari dua komponen yaitu redaman geometrik dan redaman bahan. Redaman geometrik dipengaruhi kuat oleh tipe dan likasi sumber gelombang dan redaman bahan lebih dipengaruhi oleh sifat tanah dan amplitudo getaran. Dalam studi ini, auto power spectral density (spektrum energi gelombang) digunakan untuk mengukur pengurangan energi dari redaman geometrik pada media tanah yang berlapis. Energi dari sinyal gelombang seismik diperoleh dengan menjumlahkan kuadrat amplitudo sinyal dari beberapa lokasi. Divergen dari energi tersebut yang merupakan perbedaan amplitudo sinyal dapapt digunakan untuk mengidentifikasi resapan energi seismik dalam tanah. Dengan menganalisis pergerakan partikel dan energi dalam domain frekuensi, pengurangan rambatan gelombang dari suatu sumber getaran dapat diperhitungkan. Akhirnya, faktor pengurangan tanah dari beberapa lokasi tanah dan sumber gelombang yang berbeda dapat diinvestigasi dalam makalah ini.

Kata Kunci: auto-power spectral density, pengurangan, redaman tanah, seismik

ABSTRACT: Vibrations from construction activities, earthquake and traffic loading are important because they may cause damage to the adjacent structures. For the analysis of vibration related problems, it is necessary to consider the combined effect of several factors such as the characteristics of vibration sources, the site characteristics, the propagation of surface and body waves in the ground, and response of structures. Generally, the attenuation of vibrations with distance is composed of two factors: geometric damping and material damping. The geometric damping depends on the type and the location of vibration source and the material damping is related with ground properties and vibration amplitude. In this study, auto power spectral density was used for measuring energy attenuation of geometric damping in the layered soil site. The energy in a seismic wave signal is computed as the summation of the square of the signal amplitude at each point. The divergence of energy rate with respect to the signal amplitude difference can be used to discern characteristics of the energy dissipation of layered soil in the ground. By analyzing the measured particle motions and major energy component in the frequency domain, the attenuation of propagating waves generated by vibration source was characterized. Finally, soil attenuation factor from different sites and vibration sources were investigated.

Keywords: auto power spectral density, attenuation, soil damping, seismic

1 INTRODUCTION

Soil dynamic properties are important parameters used in geo-earthquake engineering analysis related to dynamic loading in low to moderate-strain levels, e.g., ground amplification during earthquake, traffic loading, vibration from construction may cause damages. Infrastructural damages may be caused by vibrations induced differential settlement as well as by vibration transmitted directly to the structures (Drabkin et al. 1996). In order to analyze vibrations related problems, it needs to consider the effect of several factors such as the characteristics of vibration sources, site characteristics, seismic waves propagation and response of structures (Massarsch 1993). Soil attenuation corresponding to soil damping ratio is one of soil dynamic properties used in the analysis of site characteristics and seismic waves propagation.

Attenuation in soil dynamics is a phenomenon that involves the interaction of several mechanisms that contributed to the energy dissipation of the seismic wave during dynamic excitation (Rix et al. 2000). Soil attenuation parameter is able to be determined by the radiation/geometric and material damping of the soil structure. The radiation/geometric damping depends on the type and location of the vibration source and the material damping is related to soil properties and vibration. The parameter can be in situ evaluated by using seismic methods, i.e., measurement of wave velocities propagating through soil medium.

The objective of this paper is to present the measurement of energy attenuation of seismic waves on the layered sites using the auto power spectral density. This method is effective used for evaluating in-situ attenuation factor of soil structures. Results from field study carried out at unsatured soil site are also presented.

2 RESEARCH METHODOLOGY

2.1 *Basic of Auto Power Spectral Density (PSD)*

Auto power spectral density (PSD) is the frequency response of a random or periodic signal. It provides the information of average power which is distributed as a function of frequency. The PSD is deterministic, and for certain types of random signals, $x(t)$, i.e., signals recorded from seismic waves propagation is independent of time. This is useful because the Fourier transform of a random time signal is itself random, and therefore of little use calculating transfer relationships, i.e., finding the output of a filter when the input is random). The PSD of a random time signal x(t) can be expressed in one of two ways that are equivalent to each other as follows:

1. The PSD is the average of the Fourier transform magnitude squared over a large time interval.

$$S_x(f) = \lim_{T\to\infty} E\left\{ \frac{1}{2T} \left| \int_{-T}^{T} x(t) e^{-j2\pi ft} dt \right|^2 \right\} \tag{1}$$

2. The PSD is the Fourier transform of the auto-correlation function.

$$S_x(f) = \int_{-T}^{T} R_x(\tau) e^{-j2\pi ft} dt \tag{2}$$

where

$$R_x(\tau) = E\{x(t)x^*(t+\tau)\} \tag{3}$$

The power can be calculated from a random signal over a given band of frequencies as follows:

1. Total Power in $x(t)$:

$$P = \int_{-\infty}^{\infty} S_x(f) df = R_x(0) \tag{4}$$

2. Power in $x(t)$ in range f_1 - f_2:

$$P_{12} = \int_{f_1}^{f_2} S_x(f) df = R_x(0) \tag{5}$$

2.2 *Vibration Attenuation*

The decrease in amplitude (energy density) of the vertical component of the *R*-wave with distance due only to geometric configuration is called the radiation damping and can be expressed by:

$$w_2 = w_1 \left(\frac{r_1}{r_2} \right)^n \tag{6}$$

where w_1 is the amplitude of vibration at distance r_1 from the source, w_2 is the amplitude at distance r_2 from the source and n the attenuation factor due to radiation damping which depends on the type of seismic wave, the position and size of the seismic source (Table 1). Values from both amplitudes of vibration can be taken from auto power spectral density (PSD) from field measurement.

Table 1. Attenuation radiation damping factor (n) with the source on the surface (Kim & Lee 1998).

Source Type	Induced Wave	n
Point	Body Wave	2.0
	Surface Wave	0.5
Infinite line	Body Wave	1
	Surface Wave	0

The vibration energy of *R*-wave is also dissipated during its propagation by the material damping of the geomaterial which is described by the damping ratio (ξ). An effective damping ratio of *R*-wave in layered medium can be defined and the value is frequency dependent. Its value may become very high for the first few modes of vibration.

There are several models to describe the combined effect of both the radiation and material damping. The Bornitz equation is one of the common models used and can be described by:

$$w_2 = w_1 \left(\frac{r_1}{r_2} \right)^n e^{-\alpha(r_1 - r_2)} \tag{7}$$

where α is the attenuation coefficient of the material (m^{-1}).

The attenuation coefficient of material depends on the type of material and the frequency of vibration. The estimated value of the attenuation coefficient can be obtained using the *R*-wave velocity (V_R), the frequency of vibration (f) and the damping ratio (ξ) using the following equation:

$$\alpha = \frac{2\pi f \xi}{V_R} \tag{8}$$

From the above relationship, the attenuation coefficient linearly increases with the vibration frequency and is inversely proportional with the *R*-wave velocity.

Alternatively, the independent-frequency attenuation coefficient (Athanasopoulos et al. 2000) can be obtained by writing Eq.8 in the form:

$$\alpha_0 = \frac{\alpha}{f} = \frac{2\pi\xi}{V_R} \tag{9}$$

2.3 *Experimental Set Up*

In this study, the spectral analysis of surface wave method was employed to collect the seismic surface wave data for soil sites evaluation. A configuration set up on the SASW measurement is shown in Figure 1. An impact source of 4 to 8 kg was used to generate seismic waves. These waves were then received using two 1 Hz and 4 Hz frequency natural vertical geophones. Thus, they were recorded by using a set of spectrum analyser for processing.

Several configurations at 0.5, 1, 2, 4, 8 and 16 m of the receiver and the source spacings were required in order to sample different soil depths. The configuration used in this measurement was the mid-point receiver spacings. In this configuration, the short receiver spacings with a high frequency source were used to sample the shallow layers of the soil profile while the larger receiver spacings with a set of low frequency sources were employed to sample the deeper layers.

SASW measurement was carried out in several soil sites, i.e., UKM campus Bangi Malaysia, RTM Kelang Malaysia, UMY Campus Indonesia, some locations in Purwakarta-Cikampek Road Pavement and Piyungan Road Pavement.

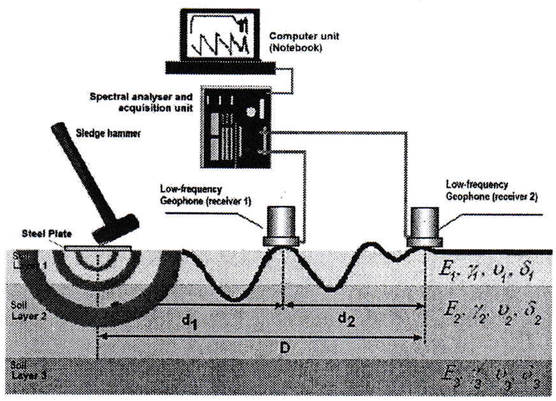

Fig 1. SASW measurement set up applied on the soil sites (Rosyidi & Taha 2012)

3 RESULTS AND DISCUSSION

3.1 *PSD from SASW Measurement*

An example of the auto power spectrum density (PSD) from 8 cm receiver spacings of SASW measurement is shown in Fig. 2. Using the bandwidth criteria, the useful frequency of the signal needed is in the range of 5.8 to 35 Hz. This frequency range of waves is the effective R-waves that propagate in the soft soil layer. The energy attenuation is also visibly identified from both spectrums.

3.2 *Attenuation Analysis*

An example of the auto power spectrum density (PSD) from 8 cm receiver spacings of SASW measurement is shown in Fig. 2. Using the bandwidth criteria, the useful frequency of the signal needed is in the range of 5.8 to 35 Hz. This frequency range of waves is the effective R-waves that propagate in the soft soil layer. The energy attenuation is also visibly identified from both spectrums.

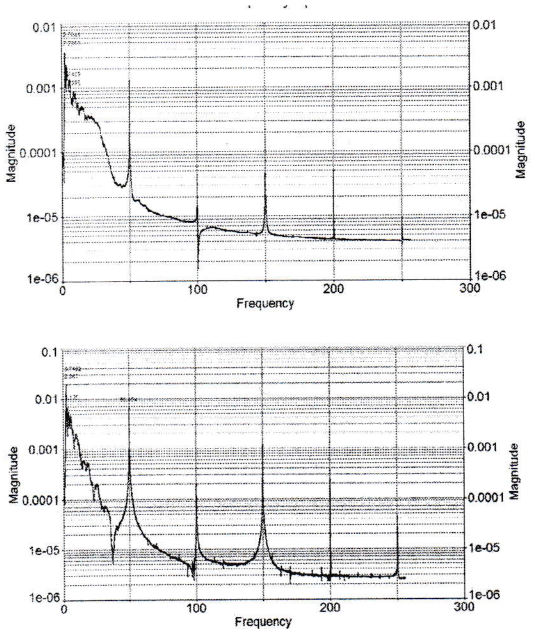

Fig. 2. PSD from SASW measurement on 8 m receiver spacing.

From Fig. 2, an experimental data trend of power spectrum ratio between both signals from PSD_2 (w_2) over the first signal magnitude of PSD_1 (w_1) versus frequency can be obtained. This ratio represents as the decay factor curve of frequency dependency from the R-wave motion (Fig. 3). An empirical correlation is subsequently performed on the experimental data of decay factor curve. The experimental regression equation is produced as:

$$\frac{w_2}{w_1} = 6.3494e^{-0.0028f} \quad (10)$$

The theoretical regression analysis of attenuation derived from Eq. 7 can then be written as:

$$\frac{w_2}{w_1} = \left(\frac{r_1}{r_2}\right)^n e^{-\alpha_0(f)\Delta r} \quad (11)$$

The best-fit curve is then established between the decay factor of the experimental data (Eq. 10) and the theoretical regression analysis equation by trial and error for different values of α_0 from visual best-fit evaluation of the two curves. The best-fit value of frequency-independent attenuation coefficient of the soil is calculated as 3.4×10^{-3} s/m at frequency of 50 to 200 Hz. The root means square error (RMSE) for this fitting curve is found to be 0.0317.

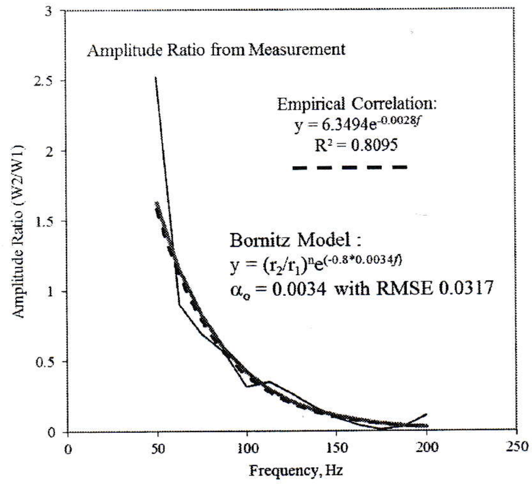

Fig. 3. Regression analysis of attenuation coefficient of the soil from auto power spectral density

The values of the frequency-independent attenuation coefficient obtained from this study were compared with experimental results that have been carried out by other researchers, such as Yang (1995), Woods (1995), Athanasopoulos et al. (2000) and Rosyidi et al. (2008) as shown in Fig.4 and Fig.5. Woods and Jedele (1985) classified soil groups from the frequency-dependent attenuation of the 5 Hz vibration. The attenuation factor of unsaturated soft soil from this study falls into Class 1 (soft soil) using Woods and Jedele (1985) classification. In general, the results are also in good agreement with Anthanasopoulos et al. (2000) that developed the range of attenuation coefficient for soils. The attenuation coefficient obtained in this study is still within the upper and lower bound of the Anthanasopoulos's (2000):

$$\alpha_0 = 3.17 \times 10^{-3} \times e^{-\frac{Vs}{500}} \text{ (best-fit)} \quad (11)$$

$$\alpha_0 = 1.15 \times 10^{-3} \times e^{-\frac{Vs}{500}} \text{ (lower bound)} \quad (12)$$

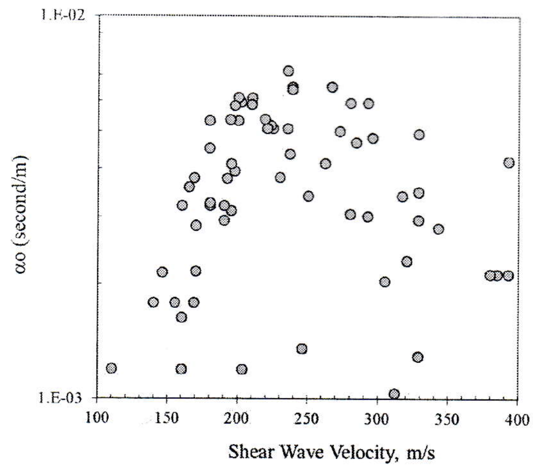

Fig.4. Results of independent frequency of attenuation coefficient from PSD and Bornitz attenuation analysis

Rosyidi et al (2008) observed soil attenuation coefficient of the subgrade material using the spectral analysis of surface waves (SASW) method. From their study, the average attenuation of residual soil subgrade was found 1.58×10^{-3} s/m ranging between 1.018 – 2.145 $\times 10^{-3}$ s/m. The result can be classified into Class 1 (soft soil).

Comparing to study conducted by Yang (1995) which also studied the frequency-independent attenuation coefficient for soil ranging from loose sand and soft clays to rock. Fig. 5 shows that the attenuation factor of this study is close to the upper bound of the attenuation coefficient range obtained by Yang (1995) for unsaturated loose sand material which is most likely due to the difference in material.

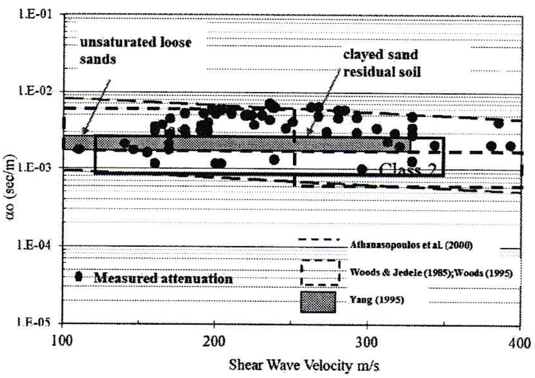

Fig.5. Attenuation factor from this study compared to the attenuation curve from other researchers.

4 CONCLUSIONS

In this paper, an auto power spectrum density (PSD) technique was used for energy attenuation analysis of soil. The attenuation decay of seismic waves propagating in soil media generated from the ratio of amplitude which is calculated from the PSD. Soil attenuation is then obtained using the Bornitz equation. A good correlation was obtained between the attenuation factor obtained from this study compared to the previous studies.

Thus, it is shown that the characterization of the soil dynamics properties in terms of attenuation coefficient can be satisfactory obtained using the Auto-PSDW method with SASW method as a tool for data collection from the field measurement. In addition, this method has the advantage of being fast and non-destructive.

ACKNOWLEDGEMENTS

The authors would like to give our sincere appreciation to the Ministry of Research, Technology and Higher Education for supporting this research through PUPT Grant 2015/2016.

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